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ACTIVE FRACTIONS OF ORGANIC MATTER IN SOILS WITH DIFFERENT TEXTURE

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Summary—Relationships between soil organic C (SOC), soil microbial biomass C (SMBC), mineralizable C and N during a 21 d incubation, and basal soil respiration (BSR) were evaluated on eight soil types from Texas that varied in soil texture (7–45% clay) and organic matter. The portion of SOC as SMBC increased with increasing clay content, whereas the relationships of mineralizable C and N and BSR to SOC were not affected by soil texture. The ratio of BSR-to-SOC averaged 1.4 ± 0.4 mg mineralizable C g^{-1} SOC d^{-1}. The amount of mineralizable C and N and BSR per unit of SMBC, however, decreased with increasing clay content, indicating that the soil microbial biomass (SMB) was more active in coarse-textured soils than in fine-textured soils. The average specific respiratory activity was 29 mg mineralizable C g^{-1} SMBC d^{-1} with 10% clay and 11 mg mineralizable C g^{-1} SMBC d^{-1} with 40% clay. The C-to-N ratio of the mineralizable fraction was 10 ± 3 and not affected by soil texture. The established relationships between active soil organic matter (SOM) fractions and soil texture could be used in models predicting SOM turnover. Published by Elsevier Science Ltd

INTRODUCTION

Knowledge of SOM turnover is important for understanding C sequestration, nutrient cycling and biophysical attributes of land management systems within particular ecological and climatic regions. Soil texture can have an influence on the turnover of SOM, whereby clay- and silt-sized particles with high surface activity may physically and chemically protect SOM from decomposition, perhaps due to isolation within and between soil microaggregates (Tisdall and Oades, 1982; Hassink *et al.*, 1993). Soil with 2% clay had a greater turnover of root-derived C during a 6-wk incubation than soil with 37% clay (Merckx *et al.*, 1985). However, using 10 soils with different texture (19–38% clay), Gregorich *et al.* (1991) observed no effect of soil texture on decomposition of glucose. Fine-textured soil (>40% clay) contained from 1.2–1.5-fold more SOC and from 2.5- to 3.5-fold more SMBC than coarse-textured soil (<15% clay) (van Veen *et al.*, 1985; van Gestel *et al.*, 1991). Higher SOC content in fine-textured compared to coarse-textured soils may be due to differences in C input, rather than long-term decomposition dynamics, since fine-textured soils tend to be more fertile than coarse-textured soils due to likely differences in water storage capacity. Greater SMBC with increasing clay content may be due to increased SOC content, rather than to protection of SMB by clay, since the amount of SMBC is often related to SOC content (Franzluebbers *et al.*, 1995c). In other cases, the relationship between SOC and SMBC has been weak (Sparling, 1981; Kaiser *et al.*, 1992), suggesting that interactions between C input, SOC, SMBC and clay content may confound relationships between SOM pools and soil texture.

Quantitative relationships between active SOM pools and soil texture are lacking and limit the predictability of SOM dynamics within regions having major differences in soil texture, such as the warm, sub-humid to humid agroecological zone in central and eastern Texas. We determined SOC, SMBC and mineralizable C and N in several soils with different texture having a range of SOM contents within each soil.

MATERIALS AND METHODS

Five to eight soil samples, differing in SOC content due to previous management and depth, were collected at each of eight locations in central and eastern Texas between 1991 and 1994 (Table 1). Mean annual temperature varies from 14°C in Bushland to 22°C in Corpus Christi. Mean annual precipitation varies from 500 mm in Bushland to 1200 mm in Overton.

Soil was air-dried and sieved to pass either a 2-mm screen (Bowie, Windthorst, and Weswood soils) or a 5-mm screen (Orelia, Pullman, Burleson, Krum

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Table 1. Soil classification, physical and chemical properties, and management systems of eight soils from Texas

USDA soil classification	Location	Clay	Sand	SOC[a]	pH	No. of samples	Land management / sampling depth / time
		%	%	mg g^{-1}			
Bowie fine sandy loam (fine-loamy siliceous, thermic Plinthic Paleudult	Overton	7	74	11.6 ± 6.9	5.9	8	Bermudagrass [*Cynodon dactylon* (L.) Pers.]; poultry manure applied at 0, 10, 20 and 40 g N m^{-2}; 0–50 and 50–100 mm soil depths; early spring 1994
Windthorst fine sandy loam (fine, mixed, thermic Udic Paleustalf)	Stephenville	12	66	13.3 ± 6.3	6.5	8	Bermudagrass; cattle manure applied at 0, 10, 20 and 40 g N m^{-2}; 0–50 and 50–100 mm soil depths; early spring 1994
Orelia sandy clay loam (fine-loamy, mixed, hyperthermic Typic Ochraqualf)	Corpus Christi	27	56	7.1 ± 1.2	8.0	5	Maize (*Zea mays* L.); conventional disk, moldboard and no tillage; 0–50, 50–125 and 125–200 mm soil depths; pre-planting 1994
Pullman silty clay loam (fine, mixed, thermic Torrertic Paleustoll)	Bushland	36	13	9.9 ± 1.6	6.0	8	Wheat (*Triticum aestivum* L.) and sorghum [*Sorghum bicolor* (L.) Moench]; stubble mulch and no tillage; 0–75, 75–150 and 150–300 mm soil depths; spring 1993
Weswood silty clay loam (fine-silty, mixed, thermic Fluventic Ustochrept)	College Station	36	11	11.9 ± 4.2	8.2	5	Wheat, sorghum, and soybean [*Glycine max* (L.) Merr.]; conventional disk and no tillage; 0–50, 50–125, and 125–200 mm soil depths; early winter 1991
Burleson silty clay (fine, montmorillonitic, thermic Udic Pellustert)	Taylor	40	15	31.1 ± 15.6	8.1	7	Cotton (*Gossypium hirsutum* L.), sorghum, and bermudagrass; abandoned cattle feeding area; 0–100 and 100–200 mm soil depths; early winter 1994
Krum clay (fine, montmorillonitic, thermic Udertic Haplustoll)	Hillsboro	44	17	12.4 ± 2.1	8.2	8	Cotton, sorghum, and bermudagrass; 0–100 and 100–200 mm soil depths; early winter 1994
Branyon clay (fine, montmorillonitic, thermic Udic Pellustert)	Hillsboro	45	19	21.0 ± 4.7	8.1	8	Cotton, sorghum, and bermudagrass; 0–100 and 100–200 mm soil depths; early winter 1994

[a]Soil organic carbon (mean $\pm$ standard deviation) of the 5–8 samples..

and Branyon soils). Soil texture was determined using the hydrometer method (Gee and Bauder, 1986). Soil pH was determined using a glass electrode in a 1:2 soil:water suspension. A subsample was further ground (0.5 mm) for determination of SOC with the modified Mebius method (Nelson and Sommers, 1982).

Mineralizable C and N were determined from aerobic incubations at 25°C in 1-l canning jars with differences in soil subsample weight, water content and sampling times for each soil type (Table 2). Soil water content was adjusted to near field capacity for each soil type. The CO_2 trapped in a container of alkali was determined by titration four to five times during the incubation (Anderson, 1982). Inorganic soil N concentration was determined from different subsamples removed at four to six times during the incubation. Soils (all except Weswood) were oven-dried (60°C, 48 h) to stop microbial activity and sieved (2 mm) before shaking a 7-g subsample with 28 ml of 2 M KCl for 30 min. The filtered extract was analyzed for NH_4–N and NO_3–N + NO_2–N using autoanalyzer techniques (Bundy and Meisinger, 1994). Inorganic N concentration of the Weswood soil was determined in an auxiliary study incubated under the same conditions, except that a 10-g subsample received 1 ml of a glucose solution (200 mg kg^{-1} soil) at each retrieval time, incubated for an additional 3 h at 25°C, frozen, and stored at −20°C prior to extraction for mineral N with 40 ml of 2 M KCl. The 3-h incubation with glucose was not expected to alter the estimate of mineralizable N since all samples at each sampling time were treated the same. No difference in NO_3–N concentration between subsamples receiving arginine-glucose and glucose only was observed (Franzluebbers *et al.*, 1996), suggesting minimal NO_3 transformation. The

Table 2. Incubation conditions for eight soils during the determination of soil microbial biomass C and mineralizable C and N

Soil	Subsample weight	Soil water content	Sampling times for CO_2	Sampling times for inorganic N
	g	g g^{-1}	days	days
Bowie fsl	40	0.075	1,3,10,20,30	0,10,20,30
Windthorst fsl	40	0.125	1,3,10,20,30	0,10,20,30
Orelia scl	20	0.250	1,4,10,27	0,4,10,27
Pullman sicl	20	0.325	1,4,10,27	0,4,10,27
Weswood sicl	20	0.300	1,3,6,10,15	0.2,1,3,6,10,15
Burleson sic	20	0.400	1,4,10,27	0,4,10,27
Krum c	20	0.425	1,4,10,27	0,4,10,27
Branyon c	20	0.450	1,4,10,27	0,4,10,27

increase in NH_4–N during the 3-h incubation ranged from 0 to 6 mg kg^{-1}.

Mineralizable C was described with a non-linear regression equation of the form:

$$C_t = C_f(1 - e^{-kt}) + lt$$

where C_t = cumulative C mineralization (mg C kg^{-1} soil) at time t (d), C_f = C mineralization potential of the flush after rewetting of dried soil (mg C kg^{-1} soil), k = non-linear mineralization constant (d^{-1}), and l = linear mineralization constant (mg C kg^{-1} soil d^{-1}). Mineralizable N was described with a non-linear regression equation of the form:

$$N_t = N_i + N_0(1 - e^{-kt})$$

where N_t = inorganic N concentration (mg N kg^{-1} soil) at time t (d), N_i = initial inorganic N concentration (mg N kg^{-1} soil), N_0 = N mineralization potential (mg N kg^{-1} soil), and k = non-linear mineralization constant (d^{-1}). Individual C and N equations for each soil sample were used to predict cumulative C mineralization and net N mineralization at 21 d of incubation, hereafter referred to as mineralizable C and N. Basal soil respiration was calculated as the rate of C mineralization from 10 to 21 d. The flush of CO_2 due to rewetting of dried soil was 94 ± 9% complete at 10 d, as predicted by the non-linear regression equation described above.

Soil microbial biomass C was determined according to the procedure of Jenkinson and Powlson (1976) on dried soil that was conditioned for 10 d under the same conditions as for the determination of mineralizable C and N. The CO_2–C evolved from the fumigated sample (trapped in 0.5 to 1 M KOH) without subtraction of a control was divided by an efficiency factor of 0.41 (Voroney and Paul, 1984).

An estimate of the effect of SOC and SMBC on other biochemical properties was derived from regression analysis using the general linear model procedure of SAS (SAS Institute Inc., 1990). Regression analysis was performed on pooled data (i.e. 57 observations) to obtain a common intercept, but unique slopes for each of the eight soil types for relationships of: (i) SOC with SMBC, mineralizable C and N, and BSR; (ii) SMBC with mineralizable C and N and BSR; and (iii) mineralizable N with mineralizable C. Pooled analysis was deemed necessary because the range in SOM contents was small in two soil types. The resulting slopes between the biochemical properties were then used in a correlation with clay content. Clay content was highly correlated (r = 0.93) with clay + silt content, and therefore, only clay was considered in the textural analysis.

RESULTS AND DISCUSSION

The portion of SOC as SMBC increased from an average of 73 mg SMBC g^{-1} SOC with 10% clay to 115 mg SMBC g^{-1} SOC with 40% clay (Fig. 1).

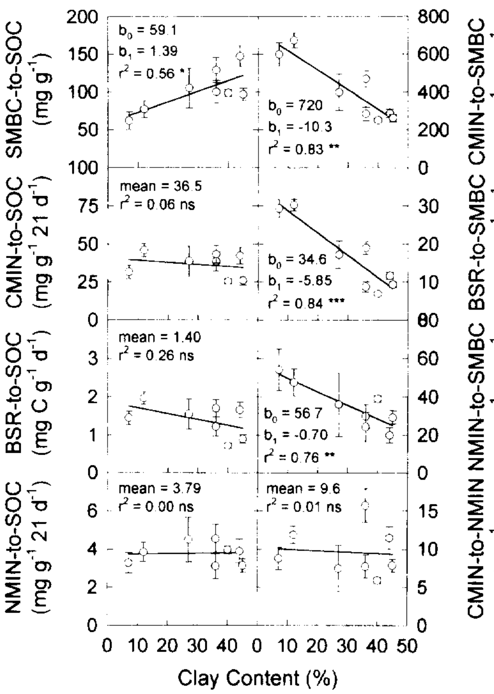

Fig. 1. Relationships between soil organic C (SOC), soil microbial biomass C (SMBC), mineralizable C during 21 d (CMIN), mineralizable N during 21 d (NMIN) and basal soil respiration (BSR) in eight Texas soils differing in texture. (b_0 is the intercept and b_1 is the slope. Error bars are standard error. *, **, and *** following coefficient of determination (r^2) indicate significance at $P \leq 0.1$, $P \leq 0.01$, and $P \leq 0.001$, respectively. When the relationship of a biochemical property with clay content was not significant (NS), only the mean was reported.)

Soils high in clay content appear to maintain a larger fraction of SOC as SMBC, perhaps due to reduced fluctuation in soil water content or protection of microorganisms from faunal grazing (Rutherford and Juma, 1992; Hassink *et al.*, 1993). The analysis of changes in the portion of SOC as SMBC with clay content, using several soil samples with a wide range of SOC contents within each soil textural class, affirms previous observations of greater SOC as SMBC with increasing clay content obtained with single samples of two soils varying in texture in Australia (van Veen *et al.*, 1985; van Gestel *et al.*, 1991) and 25 Dutch grassland soils (Hassink, 1994a). Using single values of SMBC-to-SOC ratio, Kaiser *et al.* (1992) using 27 soils from Germany and Sorensen (1983) using four soils from Denmark also found an increase in the portion of SOC as SMBC with increasing clay content. When SMBC data from Kaiser *et al.* (1992) were calculated in the same manner as in our study, the portion of SOC as SMBC was 37–47% of those in our study (62% with a direct comparison using single values from our study). The lower portion of SOC as SMBC obtained in Germany may be due to a lower annual temperature and higher ratio of annual precipitation-to-evaporation than in Texas, similar to the effect of macroclimate on SMBC reported by Insam *et al.* (1989).

Ratios of mineralizable C-to-SOC and mineralizable N-to-SOC were not affected by clay content (Fig. 1). Mean mineralization rates were 37 ± 8 mg CO_2–C g^{-1} SOC 21 d^{-1} and 3.8 ± 0.6 mg inorganic N g^{-1} SOC 21 d^{-1}. The C-to-N ratio of the mineralizable fraction averaged 9.6 ± 3.2 for the eight soils (Fig. 1), which was within the range of C-to-N ratios commonly observed for soils in other regions (van Veen *et al.*, 1985; Juma, 1993; Hassink, 1994a). In Dutch grassland soils, there was also no effect of soil texture on the portion of SOC as mineralizable C, but the portion of total N as mineralizable N decreased with increasing clay content (Hassink, 1994b). The availability of SOC for mineralization by microorganisms does not appear to be affected by soil texture. While total SOM tends to increase with clay content due to physical and chemical binding (Tisdall and Oades, 1982), these mechanisms of protection do not appear to be significant for the readily mineralizable portion of SOM, perhaps because this is a relatively small pool (McGill *et al.*, 1986; Nelson *et al.*, 1994).

The rate of BSR per unit of SMBC with the wide range of SOM contents in each soil type was greatest in coarse-textured soils (Figs 1 and 2). Ratios of mineralizable C and N during 21 d of incubation to SMBC also decreased with increasing clay content (Fig. 1). The rate of BSR per unit of SMBC, also referred to as specific respiratory activity or metabolic quotient of SMBC, averaged 29 mg C g^{-1} SMBC d^{-1} with 10% clay and 11 mg C g^{-1} SMBC d^{-1} with 40% clay (Fig. 1). These data suggest that coarse-textured soils had a more active microbial population than fine-textured soils. Mineralizable C per unit of SMBC was not affected by soil texture in Dutch grassland soils, but the rate of mineralizable N per unit of SMBC decreased with clay content (Hassink, 1994a). From values reported by Kaiser *et al.* (1992), the average specific respiratory activity of SMBC using single values from 27 different soils, was calculated to be 18 mg mineralizable C g^{-1} SMBC d^{-1} with 10% clay and 12 mg mineralizable C g^{-1} SMBC d^{-1} with 40% clay. However, the correlation between specific respiratory activity and clay content was weak ($r^2 = 0.20$) in their study. The correlation between specific respiratory activity and clay content was stronger when using the eight slopes ($r = 0.92$, Fig. 1) that accounted for differences in SOM content within each soil than the correlation using individual observations ($r = 0.85$, $n = 57$).

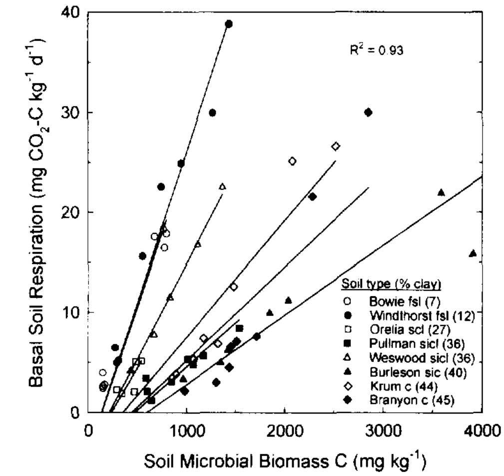

Fig. 2. Relationship between basal soil respiration and soil microbial biomass C for eight soils differing in texture.

Greater specific respiratory activity in coarse-textured soils compared with fine-textured soils may be explained in several ways. Ecosystems under stress (i.e. monoculture) are thought to have greater specific respiratory activity than more stable ecosystems (i.e. long-term crop rotations) (Anderson and Domsch, 1990). In a similar manner, greater specific respiratory activity in coarse-textured soils could indicate that the SMB is under greater stress (i.e. larger pores leading to greater water content fluctuations or to greater faunal activity for microbial predation) than in fine-textured soils, which is supported by evidence of greater faunal grazing of SMB in coarse-textured soils (Rutherford and Juma, 1992; Hassink *et al.*, 1993). Greater specific respiratory activity in coarse-textured soils may also indicate increased availability of substrates for mineralization than in fine-textured soils. The fraction of SOC as macroorganic matter (>0.15 mm) was greater in a sandy soil than a clay soil with several rates of organic input in each soil type (Hassink, 1995). Mineralizable C and N of the whole soil were correlated with the quantity of macroorganic matter in these soils. After ultrasonic dispersion, the portion of SOC that was mineralizable was greatest in the sand fraction compared to the silt and clay fractions (Gregorich *et al.*, 1989), suggesting that SOM in coarse-textured soils is of higher quality for activity of the SMB than in fine-textured soils. A further explanation of the greater specific respiratory activity in coarse-textured soils may be isolation of SMB within aggregates of fine-textured soils without access to inter-aggregate substrates, thereby increasing the proportion of less active SMB per unit of SOC. The potentially greater soil structural complexity with decreasing particle size may be more important in controlling the turnover of C and N rather than clay content *per se*, since isolation of SMB from faunal predation has been shown as a significant mechanism of protection (Rutherford and Juma, 1992; Hassink *et al.*, 1993).

Within a soil type, specific respiratory activity can be used to evaluate both long-term and seasonal effects of land management practices on SOM dynamics (Franzluebbers *et al.*, 1994, 1995a,b). However, specific respiratory activity and specific N mineralization activity can vary more than 2-fold within the same soil depending upon seasonal input of organic substrates. Therefore, time of sampling should be carefully assessed to account for changes in specific respiratory activity due to recent input of crop roots, crop residues, animal manure or green manure. Collecting soil samples at the beginning of the growing season as was done in this study, or as long as possible after organic input, would minimize differences in specific respiratory activity due to seasonal changes.

In summary, the turnover of C and N in soils of the warm, humid climate of Texas was significantly affected by soil texture. The portion of SOC as SMBC increased with increasing clay content, suggesting that the presence of increasing quantities of clay allowed SMB to proliferate, either by physical protection from faunal predation or reduced fluctuation in water availability in and around soil aggregates. Mineralizable C and N during a 21-d incubation and BSR per unit of SMBC decreased with increasing clay content. Our results, using a range of SOM contents within eight soils varying in texture, affirm the results of previous studies and provide quantitative relationships for the potential turnover of SOM in soils with different texture. Our results imply that land management practices that favor SOM accretion (i.e. conservation tillage, intensive cropping with residue returned to the soil, grain-forage rotations and integrated animal-grain systems) will increase the rate of C and N mineralization per unit of SMB and, therefore, provide plant-available nutrients more rapidly in coarse-textured than in fine-textured soils. The quantitative relationships between SOC, SMBC, BSR and mineralizable C and N could be used to model SOM dynamics for the warm, humid ecological region of the southern U.S.A. with a wide range in soil texture. Models with this degree of sensitivity are needed to address questions of land management influences of soil biogeochemical activity on soil, water and air quality.

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